### COMPARATIVE ANALYSIS OF SEVERAL VEHICLE SAFETY RATING SYSTEMS

Max Cameron Sanjeev Narayan Stuart Newstead

Monash University Accident Research Centre

Australia

**Timo Ernvall** 

Vesa Laine

University of Oulu, Road and Transport Laboratory

Finland

Klaus Langwieder

Technical University of Munich

Germany

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#### **ABSTRACT**

The paper examines the application of six vehicle safety rating systems to a common crash database, for the purpose of making a comparison of the rating results produced by each system and to develop an understanding of the differences which emerge. The rating results are compared based on rank order of crashworthiness of vehicle models, and relationships between each pair of results. Finally, the results with their respective confidence limits are used to classify each vehicle model as having inferior, not defined or superior crashworthiness, and the classification is used to compare the relative discrimination of the methods.

### INTRODUCTION

This paper describes the analysis in sub-task 1.6 of the project *Quality Criteria for the Safety Assessment of Cars based on Real-World Crashes* carried out by the Safety Rating Advisory Committee (SARAC) for the European Commission. An agreed set of crashworthiness rating systems was applied to a common crash database. Two crash databases were used: Police crash reports from three US states and accident compensation claims from Finland.

### **EXISTING SAFETY RATING SYSTEMS**

The analysis focused on the rating systems used by the following international organisations (Table 1):

- Road and Transport Laboratory, University of Oulu, Finland (Huttula, Pirtala and Ernvall 1997)
- Department of the Environment, Transport and Regions (DETR), U.K. (Transport Statistics Report 1995)

- Folksam Insurance, Sweden (Hägg et al 1992; Kullgren 1999)
- Monash University Accident Research Centre (MUARC), Australia (Newstead, Cameron and Le 2000)
- Volkswagen AG, Germany (Achmus and Zobel 1997)

As well as the above rating systems, a new proposed safety rating system designed and formulated by Newstead was also considered for the comparison analysis. The proposed new ratings are based on two-car injury crashes.

The methods used by the Insurance Institute for Highway Safety (IIHS) and the Highway Loss Data Institute in the USA were not included. This was because the two US rating systems appear to measure a combination of the crash involvement risk and crashworthiness of each model car (Langwieder, Bäumler and Fildes 1998), whereas the systems listed above aim to measure crashworthiness exclusively.

Each of the rating criteria is a measure of the risk of injury or severe injury to drivers of the specific model car when involved in a crash. This type of measure is to be expected in a crashworthiness rating system. In the first two systems, the criterion stops at the risk of injury, whereas in the other three systems the criterion goes beyond injury to measure the risk of severe injury. In the cases of the Folksam and MUARC systems, the risk of severe injury is measured in two steps: (1) the risk of injury in a crash, multiplied by (2) the risk of severe injury, given that the driver is injured. Thus all of the first four crashworthiness rating systems include a component which measures the risk of injury in a crash.

Table 1. Summary of Crashworthiness Rating Methods and Databases

Method	Database population	Database analysed	Essential characteristics	Rating criterion	Adjustment factors
UNIVERSITY OF OULU Passive safety ratings	Accidents compensated by Motor Liability Insurance in Finland. Limited information about "not guilty" drivers unless injured (age, sex not available). Includes material damage plus injury accidents. Material damage entry level undefined.	Two-car collisions between passenger cars on public roads and streets	Material damage entry criterion. (Absence of driver data related to his/her guilt.)	Absolute driver injury risk rate = number of drivers injured in the case model cars divided by the number of two-car crashes involving the case model.  [Passive Safety Rating]  Relative driver injury risk = ratio of number of driver injuries in the case model cars to the total number of driver injuries in two-car crashes involving the case model.	Driver age Driver sex Speed limit Driver guilt Accident type Injury severity
DETR Secondary car safety ratings	Police reports on personal injury road accidents in Great Britain, merged with vehicle details from the Driver and Vehicle Licensing Agency	Two-car collisions between passenger cars in which at least one driver was injured.	Personal injury entry criterion	Driver injury risk = number of collisions in which drivers of case model cars are injured divided by the number of collisions involving case model cars in which either of the two drivers is injured Driver severe injury risk = (as above, except numerator is fatally or seriously injured drivers of case model cars)	Speed limit Driver sex Driver age First point of impact
FOLKSAM Car model safety ratings	Police reports on road accidents in Sweden.  Insurance claims reported to Folksam Insurance.	Accidents involving collisions between two private cars and where at least one driver was injured. Claims for injury to adult front seat occupants.	Personal injury entry criterion	1. Driver relative injury risk (R) = number of collisions in which drivers of case model cars are injured divided by the number of collisions involving case model cars in which the driver of the opposite car is injured  2. Mean rating of serious consequences (mrsc), which is the average across injured front occupants in case model cars of their scale values reflecting the risk of death or permanent disability of at least 10%.  Rating criterion (Z) = R * mrsc	Case car mass (also used to adjust for presence of front seat passengers)  Crash year
MUARC Crashworthiness ratings	Police reports of injury crashes in Victoria, matched with TAC claims.  Police reports of injury and tow-away crashes in New South Wales and Queensland.	Drivers of light passenger vehicles involved in tow- away crashes in New South Wales or Queensland, and drivers injured in crashes in Victoria, New South Wales or Queensland	Material damage entry criterion	Driver injury risk (R) = proportion of drivers of case model cars involved in tow-away crashes who were injured.     Driver injury severity (S) = proportion of injured drivers of case model cars who were severely injured (killed or admitted to hospital).  Crashworthiness rating criterion (C) = R * S	Driver sex Driver age Speed limit Number of vehicles involved State Year of crash
VW method (Ratings method based on non- linear regression analysis)	Method not yet applied to a large-scale accident database.  Illustrated by application to 300 cases from the Medizinische Hochschule Hannover crash database	Crashes with at least one injured person. Drivers of passenger cars which had a frontal collision were analysed.	Personal injury entry criterion	Maximum AIS value of the driver.	Velocity change Use of seat belt Angle between vehicles Type of collision opponent Velocity of case car Height of driver Age of driver

Three of the rating systems (Oulu, DETR and Folksam) are based on the injury outcomes of two-car crashes involving the specific model cars. In one system (Oulu), all reported two-car crashes are considered, whereas in the others, only two-car crashes in which at least one driver was injured are analysed. The MUARC method is based on crashes of any configuration which resulted in injury or a vehicle being towed away. The databases to which the rating systems are applied vary fundamentally depending on whether they are limited to crashes involving personal injury, or whether the database also includes crashes resulting only in material damage.

All of the systems adjust the rating criterion for factors representing the differences in crash exposure, apart from the car model design, which may affect the injury outcome of the driver. Four systems adjust by driver age, three by driver sex and speed limit, and most systems adjust by the crash type in various ways. The methods used to make the adjustments vary considerably.

# NEW SAFETY RATING SYSTEM BASED ON INJURY CRASH DATA

In reviewing the existing crashworthiness rating measures, it was apparent that a number have been developed to overcome limitations in the particular data systems available. In particular, data systems where only crashes involving injury to at least one of the persons involved in the crash are reported. University of Oulu, DETR and Folksam Insurance have developed vehicle passive safety measures for such data. Measures of driver injury risk have been derived that compensate for the lack of availability of non-injury crash data.

A conceptual framework was developed by Folksam in the derivation of their injury risk measure based on the two-car crash matched-pair concept. Consider N observed two car crashes involving vehicle model k. Let  $p_{1k}$  be the average injury probability to the driver of the focus vehicle model, k, and  $p_{2k}$  be the average injury probability to the drivers of all vehicles colliding with vehicle model k. The crashworthiness of model k is measured by  $p_{1k}$  and aggressivity is measured by  $p_{2k}$ . Categorising the N observed crashes into a 2x2 table defined by injury or no injury to the focus and other vehicle drivers, Table 2 represents the expected crash frequencies, assuming  $p_{1k}$  and  $p_{2k}$ to be independent, and Table 3 represents the observed frequencies. For data systems not reporting non-injury crashes,  $n_{nnk}$  will be unknown in Table 3.

Table 2.

Expected Number of Two-car Crashes Between
Vehicle Model (k) and Other Vehicles

Drivers of vehicle model k	Drivers of o	ther vehicles	
	INJURED	NOT INJURED	
INJURED	$N p_{1k} p_{2k}$	N p <sub>1k</sub> (1-p <sub>2k</sub> )	N p <sub>1k</sub>
NOT INJURED	$N(1-p_{1k})p_{2k}$	$N(1-p_{1k})(1-p_{2k})$	N (1-p <sub>1k</sub> )
	N p <sub>2k</sub>	N (1-p <sub>2k</sub> )	N

Table 3.

Observed Number of Two-car Crashes Between
Vehicle Model (k) and Other Vehicles

Drivers of vehicle model k	Drivers of ot		
	INJURED	NOT INJURED	
INJURED	n <sub>iik</sub>	n <sub>ink</sub>	$n_{iik} + n_{ink}$
NOT INJURED	n <sub>nik</sub>	n <sub>nnk</sub>	$n_{nik} + n_{nnk}$
	n <sub>iik</sub> +n <sub>nik</sub>	$n_{ink} + n_{nnk}$	N

To overcome the problem of crashworthiness and aggressivity being confounded in the analysis of two-car injury crashes, a new measure has been developed by Newstead. The new measure of driver injury risk in vehicle model *k* is defined as follows:

$$R_{Nk} = \frac{n_{iik}}{n_{iik} + n_{nik}}$$

with the corresponding expected value given by

$$E(R_{Nk}) = p_{1k}$$

 $R_{Nk}$  is an unbiased estimator of  $p_{Ik}$  and as such is not confounded with the aggressivity parameter for vehicle model k,  $p_{2k}$ . As an unbiased estimator of absolute injury probabilities, it can be estimated using logistic regression techniques. This allows simultaneous adjustment of concomitant factors affecting injury risk, such as driver age and sex, in a way identical to that used in the current DETR and MUARC rating systems. In addition, the new injury risk measure can be combined with an injury severity measure identical to that used in the MUARC rating system. This produces a crashworthiness measure similar in construction and concept to the MUARC measure but based on injury crashes only.

## SELECTION OF A COMMON CRASH DATABASE

The ideal common database of crashes would be one on which each of the crashworthiness rating systems could be applied in full. Such a database would need to possess the following characteristics:

- Entry criterion: all types of road crash resulting in injury or material damage
- Injury outcome: record of driver (and front passenger) death, hospital admission, injury requiring medical treatment, or non-injury, and AIS scores by body region for the injured
- Adjustment factors: each of those shown in Table 1
- File size: information on sufficient numbers of crashes to provide reliable ratings on an adequate number of car models to provide reliable comparisons of the ratings results

It is unlikely that any crash database currently exists which has all these characteristics. It was decided that the VALT/Oulu database of accident compensation claims in Finland, and a database of Police crash reports from three US states were the most suitable.

## **Entry Criterion**

Within Europe, the VALT/Oulu database includes material damage crashes as well as injury crashes. Other large European databases generally cover only crashes resulting in personal injury.

Outside Europe, the database of Police crash reports from three US states, provided by IIHS, covers injury and tow-away crashes. This database includes a large number of potential adjustment factors, namely:

- driver age
- driver sex
- restraint use
- speed limit at the crash location
- number of vehicles in crash
- collision type
- geographic location (urban; rural)
- road location (intersection; non-intersection)
- point of impact on vehicle (absent in one state)
- vehicle damage (no damage; functional; disabling)
- · vehicle type

## **Injury Outcome**

The general classification of injury outcome (killed, hospital admission, injured requiring medical treatment, not injured) is commonly available in the large databases. Two of the rating systems (Folksam and VW) make use of detailed information on the individual injuries, measured on the AIS scale. AIS coding of injuries is not generally available in real crash databases, apart from special collections by investigatory teams or by insurance companies.

Modifications to the Folksam and VW systems, which retained the essence of each system, were made to allow their application to a broader database. The second component of the Folksam rating criterion (ie. mean rating of serious consequences) was replaced by a measure of injury severity, eg. proportion of injured drivers who were killed or admitted to hospital. The VW rating criterion (ie. maximum AIS of the driver injuries) was replaced by the ordinal scale of injury outcome recorded by the Police.

## **Adjustment Factors**

The first four rating systems require a similar level of detail in terms of crash exposure factors used to adjust the rating criteria for differences between the rated car models unrelated to car design (see Table 1). The VW method has made use of some detailed factors which are not usually available in large crash databases. The absence of point of impact (used in the DETR method) in one US state meant that state's data could not be considered in the common crash database from IIHS.

One adjustment factor used only in the Oulu rating system is the guilt of the driver. It appears that driver guilt is not a causative factor affecting injury outcome; it is only a source of bias affecting recording of the data in Finland. In a common crash database where this bias does not exist, such as the IIHS one, it was not necessary to adjust for driver guilt when applying the Oulu system.

### File Size

To make comparisons of the rating results produced by each method on a common database, it will be necessary to ensure that each rating produced by each method is reliable to a known degree. Reliability will increase with the size of the common database.

The crash database provided by IIHS covered 690,826 two-car crashes during 1995-1997 for which

the relevant adjustment factors were available in each case. These two-car crashes included 145,960 in which at least one driver was injured, the type of database used in the DETR, Folksam and Newstead systems. The US crash database was sufficient in magnitude to provide reliable rating results for each of the rating systems applied to it. The calculation was made only if there were at least 700 two-car crashes involving the specific make/model.

The VALT/Oulu database covered 186,125 two-car crashes in Finland during 1987-1998 for which the adjustment factors were known. Of these crashes, 12,904 resulted in at least one driver injury. Ratings were calculated only for makes/models which had been involved in at least 400 two-car crashes.

## METHODS OF COMPARISON OF RATING RESULTS

The level of comparison of the results of the crashworthiness rating systems, when applied to a common real crash database, varies according to the expectations of the consumers of these systems. These expectations may include:

- The ratings will produce the correct rank order of the crashworthiness of the car models
- 2. The ratings will provide a reliable estimate of a measure of crashworthiness for each car model
- The ratings will provide scientifically-defensible evidence (ie. not explainable by chance) that nominated car models have inferior crashworthiness and that other nominated car models have superior crashworthiness

For the first criterion, the ranks produced by each rating system, and the rank correlation between pairs of methods, were assessed. For the second criterion, the comparison was the graphical relationship between actual values of each pair of results. For the third set of comparisons, the ratings results (together with their confidence limits or statistical testing procedure) were used to classify each model car as "inferior", "not defined" or "superior" crashworthiness. The classes produced by each pair of rating systems were then compared via criteria such as the percentage of car models for which the two systems agree.

As well as making comparisons of the ratings representing the final results from each system, comparisons were made of those components/ratings which measure only the risk of injury (not necessarily severe injury). The principal rating criteria for two

systems (Oulu and DETR) measure no more than this risk, whereas the Folksam, MUARC and Newstead systems include injury risk as a component.

#### RESULTS

## Effect of Adjustment of the Existing Ratings

Using each method in Table 1, adjusted and raw (unadjusted) crashworthiness ratings were computed for makes/models that satisfied the selection criterion to ensure that the ratings are reliable. The US crash database allowed 373 makes/models to be rated and the VALT/Oulu database allowed 141 makes/models.

The relationship between each of the adjusted and unadjusted ratings, together with their rank correlation, is shown in the Figures 1-4, based on the US crash database. These display the principal rating criterion used by each rating organisation; the effects of the adjustment process on the rating components and supplementary criteria were similar.

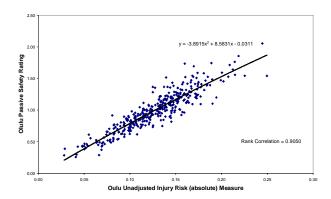


Figure 1. Relationship Between Adjusted and Unadjusted Oulu Passive Safety Ratings (US data)

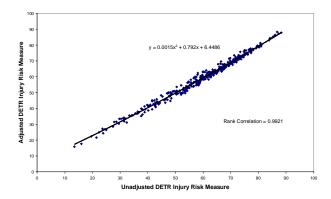


Figure 2. Relationship Between Adjusted and Unadjusted DETR Injury Risk (US Data).

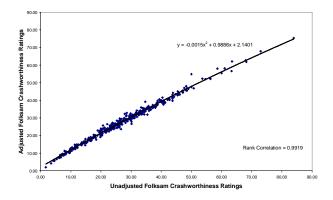


Figure 3. Relationship Between Adjusted and Unadjusted Folksam Crashworthiness Ratings (US Data).

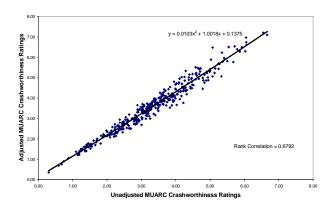


Figure 4. Relationship Between Adjusted and Unadjusted MUARC Crashworthiness Ratings (US Data).

For presentation purposes, a quadratic regression line was fitted to the data to demonstrate the degree of linearity of the relationship. The equation of the fitted regression line is also shown on each figure.

The results of the adjustment using the VW method were not available for inclusion in this paper, but will be included in the SARAC report on sub-task 1.6.

### **Adjustment of Newstead Crashworthiness Ratings**

The Newstead method used all of the relevant and unique factors available in the US crash database to adjust the injury risk and injury severity probabilities. The adjustment factors considered were:

- driver sex
- driver age (<=25 years, 26-59 years, >=60 years)
- speed limit (<50mph, >=50mph)
- road location of crash
- rural/urban geographic location

### vehicle damage

When the Newstead method was applied to the Finnish database, vehicle damage was not included as an adjustment factor because it was not available. The relationship between the adjusted and unadjusted ratings based on the US data is shown in Figure 5.

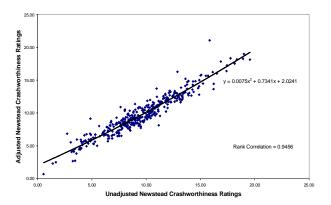


Figure 5. Relationship Between Adjusted and Unadjusted Newstead Crashworthiness Ratings (US Data).

# Comparison of the Adjusted Ratings Against a Benchmark Rating Method

To allow comparison of each of the adjusted ratings methods, a benchmark measure of crashworthiness was developed. Ideally, this should have been the "real" safety performance of each vehicle model considered, however this was unknown.

Crashworthiness Ratings Based on a Maximum Data Model (MDM) The most appropriate benchmark was ratings computed from the maximum amount of information available in each crash database. This considered both injury and non-injury crashes as well as adjusting the ratings for all relevant factors available. The resulting system was termed the "Maximum Data Model" (MDM). The base measures of injury risk and injury severity were the same as used in the MUARC method (Table 1). Logistic regression was used to adjust for the influence of other factors, apart from vehicle design, affecting injury risk and severity (which were adjusted independently). All such factors available in the common crash databases were used (the same as those used by the Newstead method). A key adjustment factor used was the vehicle damage, which is not used by any existing rating method.

The rank correlation between the adjusted and unadjusted MDM crashworthiness ratings based on

the US crash database was 0.9278 (Figure 6). Only the Oulu system had a lower rank correlation between its adjusted and unadjusted ratings (Figure 1). The effect of the adjustment process in MDM, when all available factors were considered, was to reduce the rank correlation compared with when fewer factors were used for adjustment in the MUARC rating system (Figure 4).

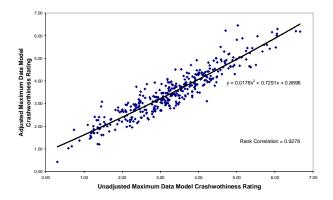


Figure 6. Relationship Between Adjusted and Unadjusted MDM Crashworthiness Ratings (US Data).

Comparison Between MDM Rating System and Other Rating Systems Tables 4 and 5 give the rank correlations between each of the adjusted rating systems and the MDM ratings. The correlations shown in bold are those where the two ratings were considered to measure the same aspect of crashworthiness, with the other correlations shown for information only.

Table 4.
Rank Correlations of Different Safety Rating
Systems using MDM Rating Criteria as the
Benchmark (US Data)

Rating Criteria	MDM Crash- worthiness Ratings	MDM Injury Risk
Severe Injury Risk Ratings		
Folksam Crashworthiness Rating	0.8150	0.6767
DETR Severe Injury Risk	0.8604	0.5737
MUARC Crashworthiness Rating	0.9426	0.7298
Newstead Crashworthiness Rating	0.9067	0.6507
Injury Risk Ratings		
Folksam Injury Risk	0.6045	0.7714
Oulu Passive Safety Rating	0.9162	0.8358
DETR Injury Risk	0.6742	0.8198
MUARC Injury Risk	0.7791	0.9379
Newstead Injury Risk	0.6825	0.8467

Table 5.
Rank Correlations of Different Safety Rating
Systems using MDM Rating Criteria as the
Benchmark (Finnish Data)

Rating Criteria	MDM Crash- worthiness Ratings	MDM Injury Risk
Severe Injury Risk Ratings		
Folksam Crashworthiness Rating	0.906	0.504
DETR Severe Injury Risk	0.931	0.326
MUARC Crashworthiness Rating	0.992	0.543
Newstead Crashworthiness Rating	0.909	0.445
Injury Risk Ratings		
Folksam Injury Risk	0.349	0.675
Oulu Passive Safety Rating	0.687	0.755
DETR Injury Risk	0.456	0.824
MUARC Injury Risk	0.562	0.999
Newstead Injury Risk	0.409	0.629

The MUARC ratings have very high correlation with the MDM ratings. In the Finnish data comparison (Table 5), this was expected because vehicle damage was not available for inclusion in MDM.

Of the methods based on injury crashes only, the DETR methods have consistently the highest correlations with the MDM ratings. The Newstead ratings had higher correlations only on the US data.

The relationship between each of the adjusted rating systems and the MDM ratings, based on the US crash data, is shown in Figures 7-8 and 10-16. The high correlation for the adjusted DETR severe injury risk measure in the Finnish data is shown in Figure 9.

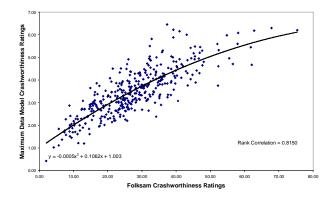


Figure 7. Relationship Between MDM and Folksam Crashworthiness Ratings (US Data).

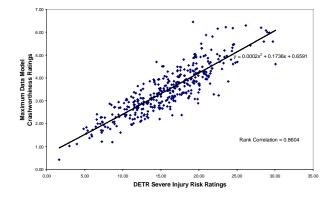


Figure 8. Relationship Between MDM Crashworthiness Ratings and DETR Severe Injury Risk Ratings (US Data).

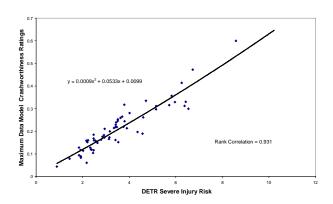


Figure 9. Relationship Between MDM Crashworthiness Ratings and DETR Severe Injury Risk Ratings (Finnish Data).

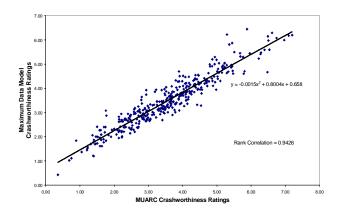


Figure 10. Relationship Between MDM and MUARC Crashworthiness Ratings (US Data).

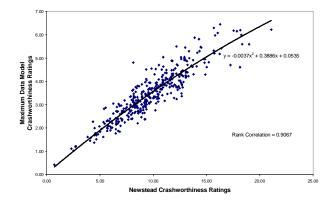


Figure 11. Relationship Between MDM and Newstead Crashworthiness Ratings (US Data).

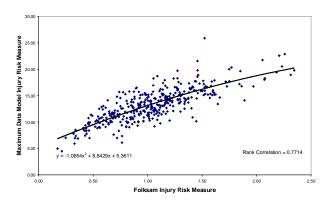


Figure 12. Relationship Between MDM and Folksam Injury Risk Measures (US Data).

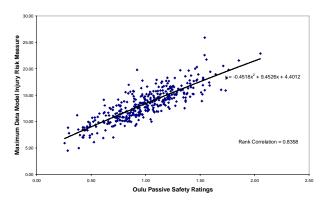


Figure 13. Relationship Between MDM Injury Risk and Oulu Passive Safety Ratings (US Data).

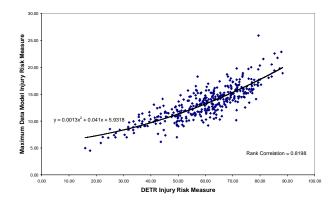


Figure 14. Relationship Between MDM and DETR Injury Risk Measures (US Data).

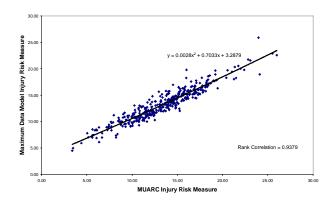


Figure 15. Relationship Between MDM and MUARC Injury Risk Measures (US Data).

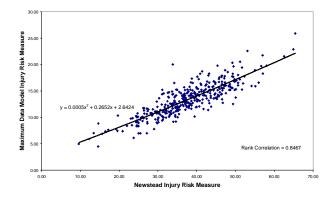


Figure 16. Relationship Between MDM and Newstead Injury Risk Measures (US Data).

### **Adjusting for Mass Effects in Car Safety Ratings**

Mass is known to have a strong relationship with vehicle safety, with vehicles of higher mass generally exhibiting superior crashworthiness in real crashes for each of the measures considered here. In the comparisons of each rating method, the correlations observed may be partly due to the strong relationship the ratings have with mass. It was considered relevant to remove the effects of vehicle mass from each rating set.

The method of adjustment for mass of the DETR, Newstead and MDM safety ratings was based on a logistic regression model of each rating against mass. The fitted logistic curve was subtracted from the original rating to provide the mass-adjusted rating. For the Oulu and the Folksam methods, because the ratings are not estimated probabilities, another method of adjustment was required. A log-linear regression of the car safety rating against vehicle mass was used instead.

Mass Effects and MDM Crashworthiness
Ratings Figure 17 based on the US crash data plots
crashworthiness measured by the MDM against mass.
The fitted logistic regression curve is also shown.
The other crashworthiness rating measures
considered were found to have similar general
relationships with vehicle mass.

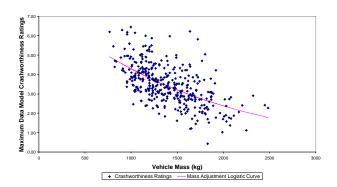


Figure 17: Relationship Between MDM Crashworthiness Ratings and Vehicle Mass (US Data).

Comparison Between Mass-adjusted MDM Rating System and Other Rating Systems Tables 6 and 7 give rank correlations between each mass-adjusted rating system and the mass-adjusted MDM ratings. The rank correlations are lower compared to the correlations observed in Tables 4 and 5. This is due to the removal of mass effects from the respective ratings. However the MUARC rating systems still have high correlation with the MDM ratings. The relationship between these mass-adjusted crashworthiness ratings is shown in Figure 18.

Of the methods based on injury crashes only, the DETR severe injury risk continues to display high correlation with the MDM crashworthiness ratings after the adjustment for mass has been made. The relationship between them is shown in Figure 19.

Table 6.
Rank Correlations of Different Mass-Adjusted
Safety Rating Systems using Mass-Adjusted MDM
Rating Criteria as the Benchmark (US Data)

Rating Criteria	MDM Crash- worthiness Ratings	MDM Injury Risk
Severe Injury Risk Ratings		
Folksam Crashworthiness Rating	0.6915	0.2702
DETR Severe Injury Risk	0.7653	0.1576
MUARC Crashworthiness Rating	0.9026	0.4576
Newstead Crashworthiness Rating	0.8559	0.3637
Injury Risk Ratings		
Folksam Injury Risk	0.2386	0.4709
Oulu Passive Safety Rating	0.8553	0.6278
DETR Injury Risk	0.4057	0.5985
MUARC Injury Risk	0.5844	0.8664
Newstead Injury Risk	0.4306	0.6654

Table 7.
Rank Correlations of Different Mass-Adjusted
Safety Rating Systems using Mass-Adjusted MDM
Rating Criteria as the Benchmark (Finnish Data)

Rating Criteria	MDM Crash- worthiness Ratings	MDM Injury Risk
Severe Injury Risk Ratings		
Folksam Crashworthiness Rating	0.872	0.176
DETR Severe Injury Risk	0.914	0.105
MUARC Crashworthiness Rating	0.992	0.389
Newstead Crashworthiness Rating	0.795	0.183
Injury Risk Ratings		
Folksam Injury Risk	0.140	0.353
Oulu Passive Safety Rating	0.639	0.584
DETR Injury Risk	0.319	0.586
MUARC Injury Risk	0.413	0.995
Newstead Injury Risk	0.159	0.317

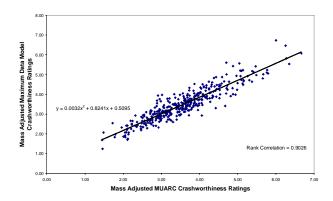


Figure 18. Relationship Between Mass-adjusted MDM and Mass-adjusted MUARC Crashworthiness Ratings (US Data).

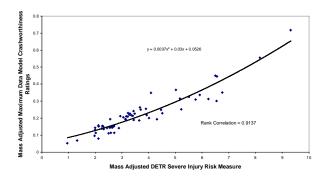


Figure 19. Relationship Between Mass-adjusted MDM Crashworthiness Ratings and Mass-adjusted DETR Severe Injury Risk Ratings (Finnish Data).

## **Comparison of Presentation of Rating Results for Vehicle Models**

The adjusted crashworthiness rating were also compared by their ability to rank the most common vehicle models, and by the classification of each vehicle model as having a "inferior" or "superior" safety rating.

The first comparison was made by ranking the rating results of 20 vehicle models most frequently involved in two-car crashes in the US. The 20 models most involved in crashes were chosen in order to minimise, as far as possible, the effects of random variation on the rating estimates. Figure 20 shows the rank order of the ratings from each of the methods based on a measure of severe injury risk as the criterion.

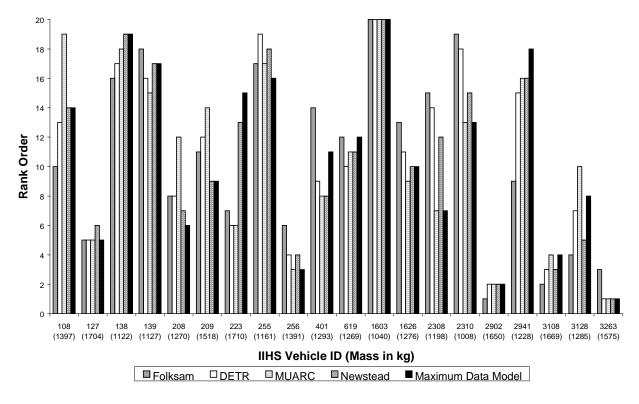


Figure 20. Rank Order of Crashworthiness Ratings For Each Vehicle Model (US Data).

The mass of each vehicle model (in kg) is also shown in brackets below each model ID. Generally, the rank order of crashworthiness suggested by each of the rating methods was similar. Some vehicle models have been ranked essentially the same by all methods whilst some have been ranked very differently. This could be due to the nature of crashes used by each method, ie. some methods are based on all crashes and some are based on injury crashes. There are other fundamental differences in the methods being compared (Table 1).

For the second comparison, classification of vehicle models into "inferior", "not defined" or "superior" was considered. The classification was based on the 95% confidence limits calculated for the crashworthiness ratings, and the respective limits compared with the all model average point estimate. Tables 8 and 9 make comparison between the MDM crashworthiness ratings and other methods of crashworthiness rating.

In the tables, "agree" signifies the proportion of vehicle models that fall in agreement in classification between the rating methods being compared. There were no cases where a rating method was found to fundamentally "disagree" with the MDM ratings, ie. it classified a vehicle model to be of "superior"

crashworthiness whereas MDM classified the same vehicle model to be of "inferior" crashworthiness, or vice versa.

### **CONCLUSIONS**

All of the crashworthiness rating systems correlate well with the ratings produced by a Maximum Data Model, which makes the maximum use of the crash data available to rate crashworthiness. Of the methods based on all crashes, the MUARC method has the strongest correlation with the MDM ratings. The DETR Severe Injury Risk rating method appears consistently the strongest of the methods based on injury crashes.

There are weaker correlations between the ratings systems and the MDM ratings when the effects of vehicle mass on the ratings are removed. However the strongest correlations described above remain relatively strong.

All but the Folksam safety ratings method correctly discriminate more than 80% of vehicle makes/models as having superior or inferior crashworthiness, as judged against the classification based on the MDM ratings.

Table 8.

Comparison of MDM Crashworthiness Ratings and Other Crashworthiness Rating Methods Based on Classification of Vehicle Models (US Data)

			Folksam Crashworthiness Ratings		Crashworthiness Injury Risk		MUARC Crashworthiness Ratings			Newstead Crashworthiness Ratings				
		Total	I	ND	S	I	ND	S	I	ND	S	I	ND	S
MDM	I	66	51	15		50	16		62	4		44	22	
Crashw.	ND	272	37	167	68	12	225	35	26	223	23	8	257	7
Ratings	S	35		5	30		8	27		3	32		9	26
	Total	373	88	187	98	62	249	62	88	230	55	52	288	33
	,		Agree	!	66%	Agree		81%	Agree	8	5%	Agree		88%

MDM – Maximum Data Model; I – Inferior, ND – Not Defined, S – Superior

Table 9.

Comparison of MDM Crashworthiness Ratings and Other Crashworthiness Rating Methods Based on Classification of Vehicle Models (Finnish Data)

			Cras	Folksam Crashworthiness Ratings			DETR Severe Injury Risk		MUARC Crashworthiness Ratings			Newstead Crashworthiness Ratings		
		Total	I	ND	S	I	ND	S	I	ND	S	I	ND	S
MDM	I	4	3	1		3	1		4			3	1	
Crashw.	ND	56	8	35	10	4	52		1	55		6	50	
Ratings	S	2			2		1	1			2		2	
	Total	62	11	36	12	7	54	1	5	55	2	9	53	0
			Agree		68%	Agree		90%	Agree	9	8%	Agree	e	85%

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